DETERMINATION OF SEDIMENT DENSITY WITH A GAMMA PROBE: A MANUAL OF THEORY, OPERATION, AND MAINTENANCE FOR TECHNICAL OPERATIONS MODEL 497

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CONTENTS

DETERMINATION OF SEDIMENT DENSITY WITH A GAMMA PROBE: A Manual of Theory, Operation, and Maintenance for Technical Operations Model 497[1]

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SUMMARY EVALUATION

The gamma probe has been used by researchers in the Agricultural Research Service from 1958. Since then, density measurements have been made under a wide range of geographic, geologic, and hydrologic conditions. In the same period, researchers in the Corps of Engineers, Bureau of Reclamation, and other organizations also have used the Technical Operations gamma probe under a variety of operating conditions.[4]

The precision of measurement is excellent, and the error in an individual determination is generally less than 1 percent. For a 1-minute count, this error amounts to 0.5 to 0.7 pound per cubic foot. With a 10-minute count, the error is reduced by $\sqrt{10}$ to 0.15 to 0.25 pound per cubic foot. No other known method of measuring densities of sediment in situ approaches this degree of accuracy and reliability.

The gamma probe is an integrating instrument. As such, the determination of sediment density is limited to materials 1 foot or more in thickness. Valid estimates of densities of materials near interfaces or banded in layers less than 12 to 18 inches thick are not obtainable. However, when used in conjunction with a dual probe, one type of which is described by the senior author (*8*),[5] complete coverage of density of sediments in situ is possible.

The equipment is moderately expensive. The Technical Operations gamma probe sells for about \$2,000; the Nuclear-Chicago Model 5920 scaler for about \$1,400. One hundred feet of 1½-inch diameter cut and threaded aluminum tubing costs approximately \$300. Accessory items are a minor expense. Auxiliary equipment, such as boats, cables, a raft, etc. vary in relation to the size and scope of the specific project.

Various techniques in the use of the gamma probe are described in this manual. Variations will do as well in particular situations. The gamma probe has been used equally well by persons wading in the sediment or working from a raft in 70 feet of water.

INTRODUCTION

The attenuation of gamma rays passing through a given medium has been used to determine the density of the material. The determination of soil and sediment densities through these techniques has already been reported (*6, 11*). One method, using a gamma probe developed for the Beach Erosion Board (*2*), has been used extensively in measuring densities of sediments (*4, 7*). The principles of operation have been tested and

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[4] During the preparation of this manual the authors received for examination copies of two other in-house manuals being prepared for use with the Technical Operations gamma probe. These were: (1) *Operation Manual for the Radioactive Sediment Density Probe*, prepared by Robert H. Livesey, U.S. Army Engineer District, Corps of Engineers, Omaha, Nebr., July, 1965. (2) *Instruction Manual for Tech/Ops Model 497—Sediment Density Probe*, prepared by Fred Witzigman, Federal Inter-Agency Sedimentation Project, St. Anthony Falls Hydraulic Laboratory, Minneapolis, Minn.

[5] Italicized figures in parentheses refer to Literature Cited on page 19.

the gamma probe used successfully in sediment surveys for several years.

The purpose of this publication is to provide the actual and the potential user of the gamma probe with: (1) an insight into the theory of operation, (2) a method of calibration, (3) complete operating instructions, (4) maintenance requirements and suggestions, and (5) an evaluation of its performance.

HISTORICAL BACKGROUND

The development of nuclear techniques for measuring density or specific gravity of materials began in the early 1950's. The availability of X-ray generators, of alpha, beta, gamma, and neutron sources, and of stable detectors, such as ionization chambers and scintillation counters, provided the impetus for this development. Development of methods to measure soil moisture by neutron moderation and to determine soil density by gamma-ray scattering proceeded at an accelerated rate following a publication by the Civil Aeronautics Administration in 1950 (*1*).

In 1952, G. W. Morgan and associates (*9*), applied for a patent on a device to determine "the density of silt or mud which has accumulated at the bottom of bodies of water." This device used the attenuation of bremsstrahlung rays from beta activation of metal foils as a means of measuring the density of sediment. The unit described was essentially a dual-probe apparatus.

In 1955, L. O. Timblin, Jr., (*12*) described the work of the Bureau of Reclamation in developing a sediment density probe. This unit used an ionization chamber (actually a personnel dosimeter pencil) placed in a probe with a radioactive source. (The ionization chamber was shielded from the radioactive source by lead.) The probe was placed in the sediment. After a suitable time interval, the probe was removed, opened, and the dosimeter removed and read. Despite the cumbersome apparatus, good experimental data were reported (*13*).

A significant advance made in 1960 is described in a report by Caldwell (*2*). This report describes the development of a gamma probe by the Beach Erosion Board, Corps of Engineers, through a contract with Technical Operations, Inc.[6] of Burlington, Mass. This instrument, with minor modifications, is the subject of this publication.

THEORY

The attenuation or absorption of a beam of gamma rays passing through a material, or absorber, follows the exponential relationship:

$$I = I_o e^{-\mu_\ell x} \tag{1}$$

where I (counts per minute) is the transmitted part of a beam of gamma rays of incident intensity, I_o(c.p.m.), which passes through an absorber of x (cm) thickness with a linear absorption coefficient of μ_ℓ(cm.$^{-1}$). The mass absorption coefficient μ_m(cm.^{2}/g.) equals μ_ℓ/ρ where ρ (g./cm.^{3}) is the density of the absorber. Substituting these values in equation 1:

$$I = I_o e^{-\mu_m \rho x} \tag{2}$$

As used here μ is the total absorption coefficient which is the sum of the macroscopic cross sections for the three processes which attenuate gamma photons: (1) photo electric effect, (2) pair production, and (3) Compton effect.

These equations are valid only when the emitted gamma photons are monoenergetic and when the absorber is homogeneous. The mass absorption coefficients μ_m for elements whose atomic numbers(Z) are less than 26, have similar values ranging from 0.109 to 0.138 cm.^{2}/g. for 0.2 Mev. photons (*2*). Hydrogen is an exception, i.e., μ_m of H = 0.243 cm.^{2}/g. Because the proportion by weight of hydrogen atoms in sediments is small, the average mass absorption coefficient in a sediment is, for practical purposes, constant.

A variation in the usual percentage of elements making up a sediment or the presence of significant weight fractions of elements with atomic numbers greater than 26 may produce a significant change in the absorption coefficient of the system. If values of μ_1, μ_2, μ_3, . . . μ_m exist because of differing photon emission energies or the heterogeneous makeup of the absorber, proportional values of I_1, I_2, I_3, . . . I_n must be obtained and added to determine total absorption.

[6] Trade names are used in this publication solely for the purpose of providing specific information. Mention of a trade name does not constitute a guarantee or warranty of the product by the U.S. Department of Agriculture or an endorsement by the Department over other products not mentioned.

In materials with similar absorption coefficients, however, and with constant geometry (a constant distance from source to detector), the attenuation of reflected and scattered photons can be expressed as a function of the material's density.

It must be remembered that the gamma probe provides only an empirical measurement of density. The attenuation processes which occur in the materials surrounding the gamma probe are extremely complex. It is not feasible to calculate gamma ray absorption on the basis of known coefficients of absorption and atomic composition. When photons are scattered and reflected, the absorption coefficients of atomic species increase as the energy of the gamma photons decreases.

Two techniques are generally used for determining densities (or thickness) of materials by gamma ray attenuation. The first method is transmission. This system (*8*) requires two probes: one contains the radioactive source; the second is a radiation detection device. This device is usually a scintillation crystal mounted on a photomultiplier tube. The use of a scintillation crystal also allows the employment of sophisticated electronic discrimination devices. Secondary, scattered, and other photons with an undesired energy are eliminated from the circuit and not counted.

The second method of determining density, using a single probe instrument, is the subject of this publication. In this method, the radioactive source and detector are separated by shielding (*2*, *7*, *8*). By general agreement, the term "gamma probe" is used to describe both the instrument and the technique of use. In operation, the gamma probe measures the flux of reflected gamma photons as well as that of secondary and scattered radiations. All measured radiation must be reflected or deflected to the detection system which is itself shielded from direct transmission of gamma rays by a lead shield.

DESCRIPTION OF EQUIPMENT

The equipment consists of: a probe, with radioactive source and detection tubes; a readout device, either a scaler or ratemeter; a source of power, usually incorporated in the scaler/ratemeter; connecting cable; tubing for suspending the probe; and assorted miscellaneous equipment which changes with the job at hand and its needs.

Gamma Probe

The gamma probe manufactured by Technical Operations Inc. is shown in figure 1. It consists of a stainless steel housing containing (in ascending order): a radioactive source (3 millicuries of radium-226); a lead shield; three Geiger-Müller detector tubes; a transistorized preamplifier circuit, including a mercury battery; and a watertight O-ring seal (figure 2). These components are mounted on a chassis which slides into and out of the housing, and is secured by screws countersunk in the casing. A watertight connector for coaxial cable and a threaded section for attaching the aluminum extension tubing are provided externally at the upper end of the probe. The probe casing and the cable connections used by Technical Operations, Inc. have been modified in figure 1.

The probe is approximately 1½ inches in diameter, 23 inches long, and weighs 11 pounds. The details of early design needs are given by Caldwell (*2*). Both probes shown in figure 1 have had the original external shell modified. The original model had a swell at the

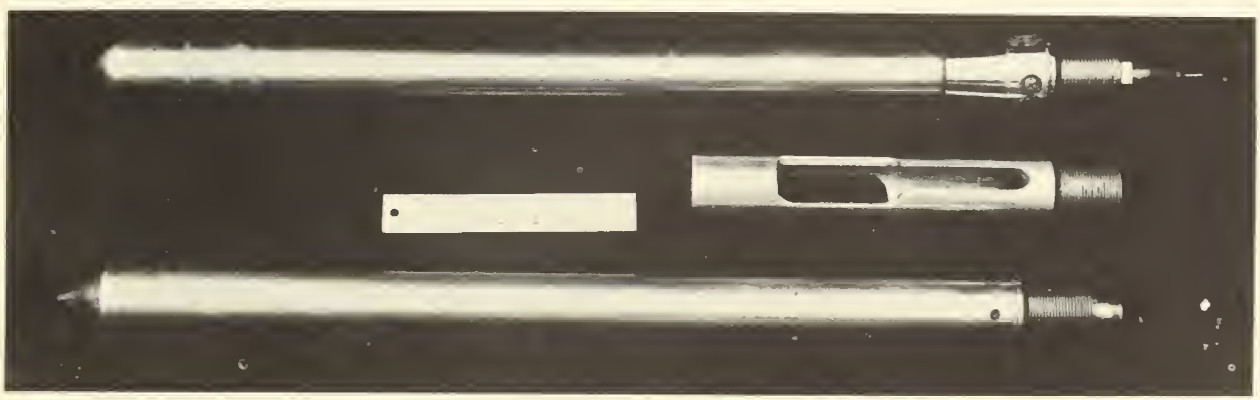


Figure 1.—Technical Operations Model No. 497 Gamma Probes. Serial No. 7 is at top and Serial No. 3 is at bottom. The small piece between the two probes is a slotted coupler section.

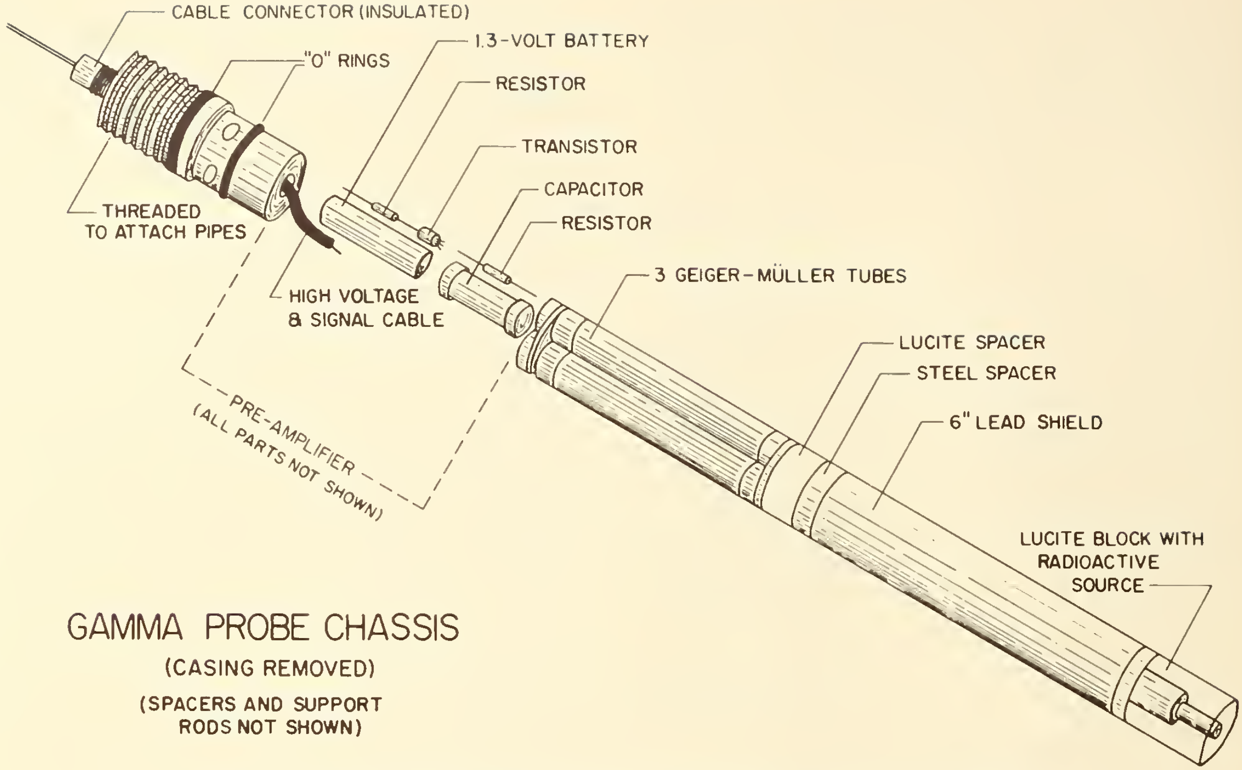


Figure 2.—Drawing of gamma probe chassis showing arrangement of internal components.

top and this was threaded to accommodate a 2½-inch pipe (fig. 3). This swell was eliminated to facilitate pushing the probe into sediments and then withdrawing it. Changes in the internal circuitry also have been made.

Counting Equipment

The gamma probe was designed to operate with a Nuclear-Chicago Model 2800 portable scaler. A Nuclear-Chicago Model 2800A or 5920 scaler can be substituted. Other scalers or rate meters can also be used, provided that they are compatible electronically and are properly connected. Two models of Nuclear-Chicago scalers are shown in figure 4. The 2800 scaler has been modified by the addition of a right-angle coaxial cable connector. This eliminates the use of the large, 6-pin connector on the 2800 scaler.

The scaler consists of a preamplifier, an amplifier, a counting circuit, a battery charging circuit, and a power supply. Readout is by Dekatron glow tubes. The timing mechanism is spring wound in the older units; battery driven in the newer 2800A or 5920 models. Because the scaler may be operated either from a 6-v. battery or from a 110-v., 60-cycle line, maintenance tests can be made in either operating mode. When used in the field, the 6-v. battery is capable of operating the probe and scaler for an 8-hour day.

The scaler accepts signals of 150 to 250 mv. and amplifies them before transmitting the pulses to the counting circuit. A factory-adjusted discriminator in the circuit eliminates those signals with an energy less than 200 mv. It is possible to adjust the discriminator setting (sensitivity) in the Nuclear-Chicago scalers. These adjustments, however, should be made only when suitable test equipment is available.

The mechanical timer provided on the Model 2800 scaler is not accurate. A stopwatch should be used to time the measuring period. With practice, an operator can become proficient in starting and stopping the scaler counting mechanism in time with the stopwatch.

Accessories

The probe is connected to the scaler by coaxial cable. Normally, 75 to 100 feet of cable are furnished with each gamma probe. The older probes were supplied with a 13/32-inch O.D. cable, Consolidated RG 8/U, 52 ohm impedance. The newer probes are equipped with a smaller and more flexible cable, Belden 8410, ¼-inch O.D. High voltage from the scaler to the probe and signals from the probe to the scaler

Figure 3.—Technical Operations Model No. 497 Gamma Probes. *A*, the original model; *B*, the ARS modification.

are transmitted over the cable. Because both the amperage of the high voltage power output and the strength of the signal are low, care must be taken in handling the cable. Cuts, sharp bends, and such may produce a short within the cable; moisture and dirt on the connectors will produce similar results. Any small impediment in the circuit will prevent power or signal transmission.

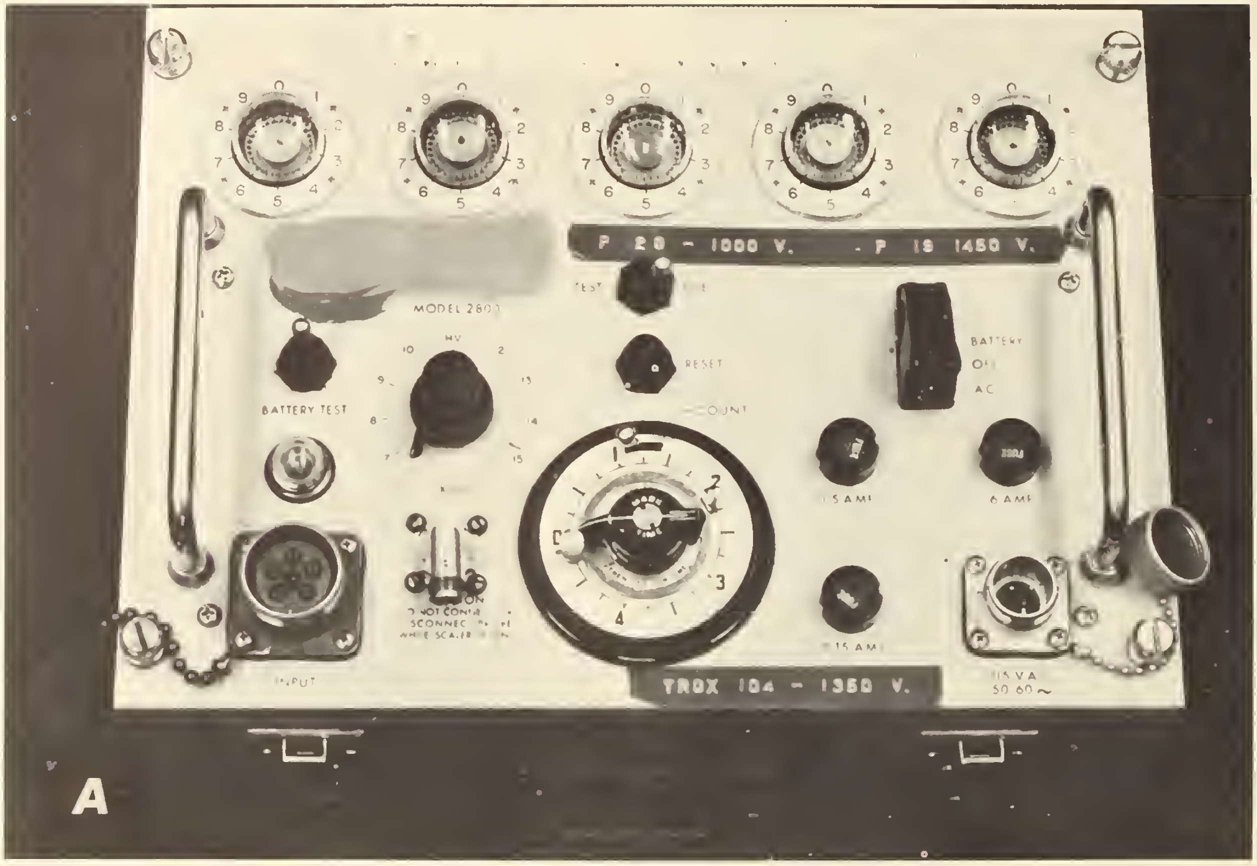
For convenient operation and for protection of the cable, the connecting signal cable is kept out of sediment whenever possible. The cable may be threaded through the number of aluminum extension tubes thought necessary for the work at hand. Next the cable is connected to both probe and scaler. With the aluminum tubing attached to the probe and with each successive section tightened by hand, the cable is kept out of the sediment. Some 18 to 20 feet of probe and extension tubing can be conveniently handled as an assembly. Additional sections can be initially threaded with the cable. When lowering the probe, they can be connected to the assembly piece by piece as needed. Similarly, when the probe is raised, they can be removed. Several methods of temporary storage of these cable-threaded extension sections have been used.

A short coupler-section of tubing is supplied with each probe (figs. 1 and 3). This coupler section has a slot in it so that the cable can be fed from the aluminum tubing when and where desired. Additional aluminum extension sections can be added or removed without threading or disconnecting the cable. The USDA Sedimentation Laboratory uses aluminum extension sections in 6- and 10-foot lengths. Other lengths can be used as well. The aluminum extension sections should be marked at convenient intervals (0.1 or 0.5 foot) to determine the submerged depth of the gamma probe easily.

The discussion in the previous paragraphs is prompted by the inconvenience to routine measurements from having to disconnect the cable. This action necessitates turning off the high voltage. When connections are made again, another warmup period is necessary.

A carrying box is also provided (fig. 5). This box has a small lead holder that shields the radioactive source when the probe is in the box. The cable and the slotted coupler section may be stored in the lid of the box. The box is plainly marked as to contents, and serves as a suitable storage and shipping container.

Persons working with the gamma probe may be required by their agencies to wear some type of personal radiation dosimeter. Usually a film badge is worn. Pencil dosimeters also can be used. In the Agricultural Research Service, a record of the time of potential radiation exposure, as well as the amount of radiation received (as indicated by the radiation dosimeter), must be maintained. This satisfies the requirements of the U.S. Department of Agriculture. The user also must meet his particular State's requirements for radiation protection and record keeping.



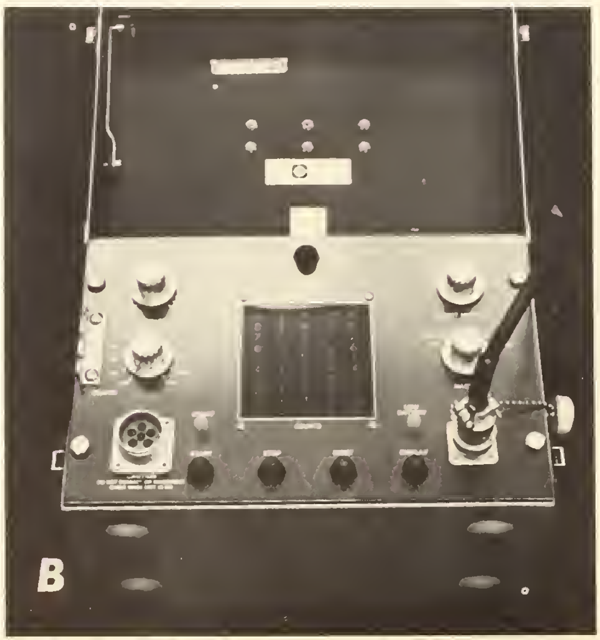


Figure 4.—Nuclear-Chicago portable scaler for use with the Technical Operations Model 497 probe.

A, The control panel of a Model 2800 scaler

B, A top view of a Model 5920 scaler.

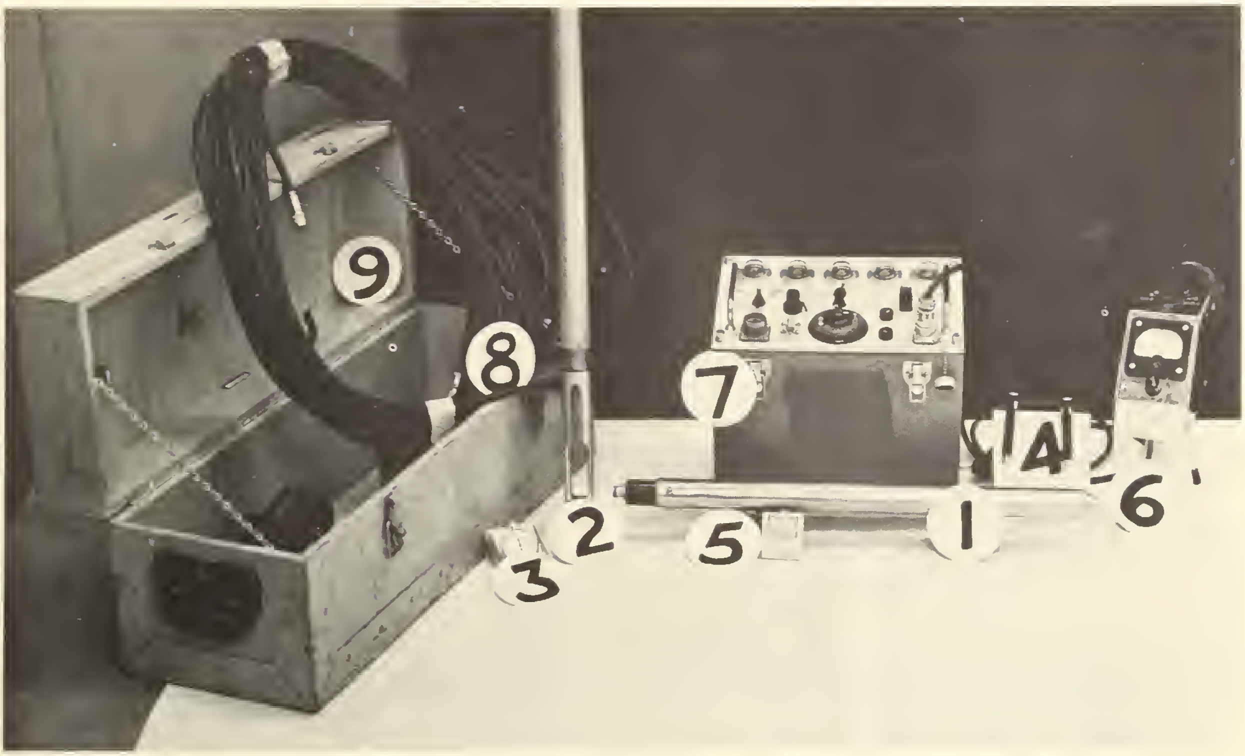


Figure 5.—Equipment used for sediment density measurements: (1) Gamma probe; (2) aluminum section with slotted coupler attached; (3) stopwatch; (4) personnel pencil dosimeter; (5) personnel film badges; (6) portable survey meter; (7) Nuclear-Chicago Model 2800 portable scaler; (8) cable; (9) carrying case containing lead shield.

Miscellaneous Equipment

Because the glow tubes on the scaler are very difficult to read in sunlight, the scaler is normally shaded. An umbrella or some other source of shade should be provided on the watercraft. The scaler will also function better if exposure to direct sunlight is minimized. The stopwatch and other small tools should be attached to the watercraft or operators with string or small chains to prevent their loss overboard. Complete specifications for the gamma probe, scaler, cable, and aluminum tubing are given in Appendix 1.

CALIBRATION

The calibration of each gamma probe is necessary, because the operating characteristics of each are slightly different. Each gamma probe has an optimum operating voltage. Technical Operations, Inc. ordinarily supplies this information with their probes. The optimum voltage, however, may change with time, and usually will change with the replacement of electronic components in the preamplifier circuit. In these cases, an operating plateau should be determined (*10*). A typical operating curve is shown in figure 6. Details of calibration procedure are given in Appendix 2.

The dial on the high voltage rheostat may not read correctly. A calibration table is provided by Nuclear-Chicago which is mounted in the lid of the scaler. Should you wish to check the high voltage applied to the Geiger-Müller tubes, an electrostatic voltmeter must be used to obtain a correct reading (fig. 7).

CAUTION: Do not hook up voltmeter when high voltage is turned on and the probe is attached.

It is the experience of the Agricultural Research Service that a laboratory calibration is made most easily and is applicable to many different field conditions. (A procedure sheet is given in Appendix 2). Standard 55-gallon steel drums are filled with the desired amount of water and soil. These are mixed thoroughly. Next the gamma flux is measured. Subsequent increments of water or soil or both provide additional points on the calibration curve. Measurements of weight and volume are made, so that the density of the mixture can be calculated.

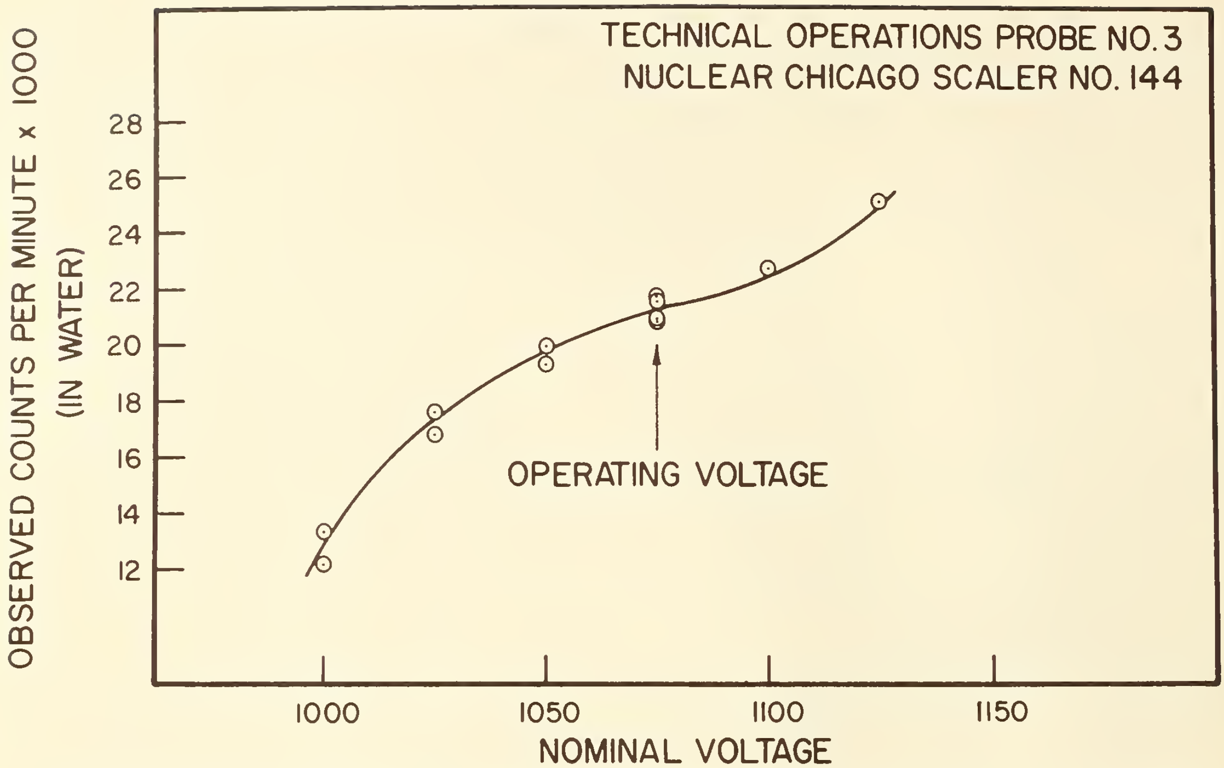


Figure 6.– Characteristic voltage-count rate curve for a Geiger-Müller tube used to determine the proper operating voltage.

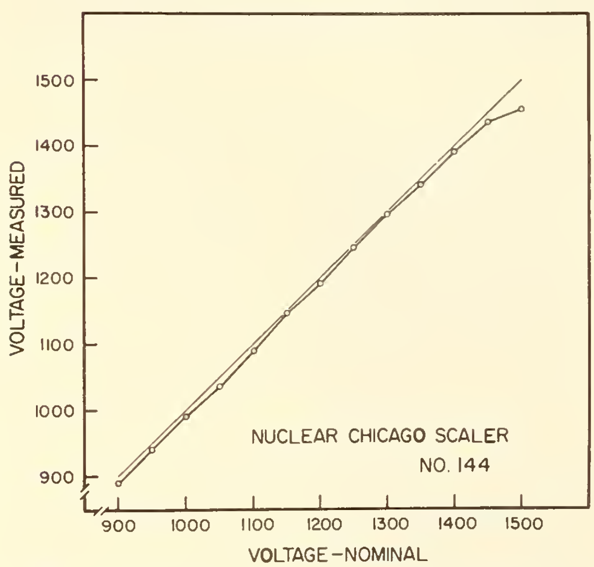


Figure 7.–Deviation of applied voltage, as measured by an electrostatic voltmeter, from nominal voltage read on Nuclear-Chicago Model 2800 scaler.

The calculated density values and observed counts per minute are plotted as a calibration curve. A sample is shown in figure 8. Densities of mixtures containing from 0 to 75 pounds of dry matter per cubic foot have been obtained experimentally. At either end of this

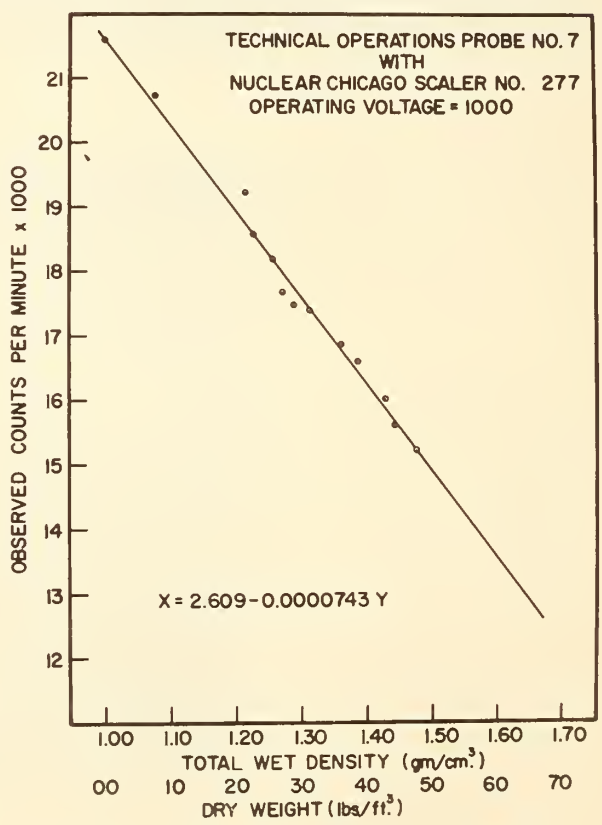


Figure 8.–A typical calibration curve for a gamma probe.

range, i.e. in very dilute suspensions and in very viscous suspensions, no significant settling of heavier material occurs. However, signficant amounts of sand tend to settle out of densities between 10 and 65 pounds per cubic foot. To prevent settling, bentonite or another material that produces a highly viscous suspension in water is added.

Density measurements made with the gamma probe depend on the reflection or scattering of the gamma photons emitted by the radioactive source. If the density of the material in a given system is low, and the thickness or size of the container is not large, some loss of emitted photons from the system occurs. A standard 55-gallon drum filled with water is not an infinite medium for the gamma probe, but the increased count achieved with a container with a larger diameter is small and insignificant. The addition of as little as 5 pounds of soil per cubic foot is enough to create an infinite volume in the standard 55-gallon drum as far as functioning of the gamma probe is concerned (*8*). The observed gamma flux in water was not used in the derivation of the equation of the calibration curve.

In calibration curves prepared by the USDA Sedimentation Laboratory, the counts per minute of measured gamma radiation (flux) are plotted as a function of the total wet density of the system. The wet density is plotted as grams per cubic centimeter (apparent specific gravity). The slope of the line denoting response in counts per minute to changes in density (radiation flux intensity) will usually be the same. However, the absolute counting level will differ with the individual probe and other operating conditions. For engineering use, a plot is also included of the dry weight of sediment in pounds per cubic foot. This conversion assumes a specific gravity of 2.65 for the dry sediment. Both scales are shown in figure 8.

Although temperature does not directly affect the performance of the gamma probe, it does influence mechanical action of the scaler to some degree and performance of the solid state components. A change also may occur when the electronic components of the gamma probe, or scaler, are replaced. A change in cable length or size may produce small changes in the response of the gamma probe (fig. 9). Recalibration of the probe is necessary after replacement of transistors,

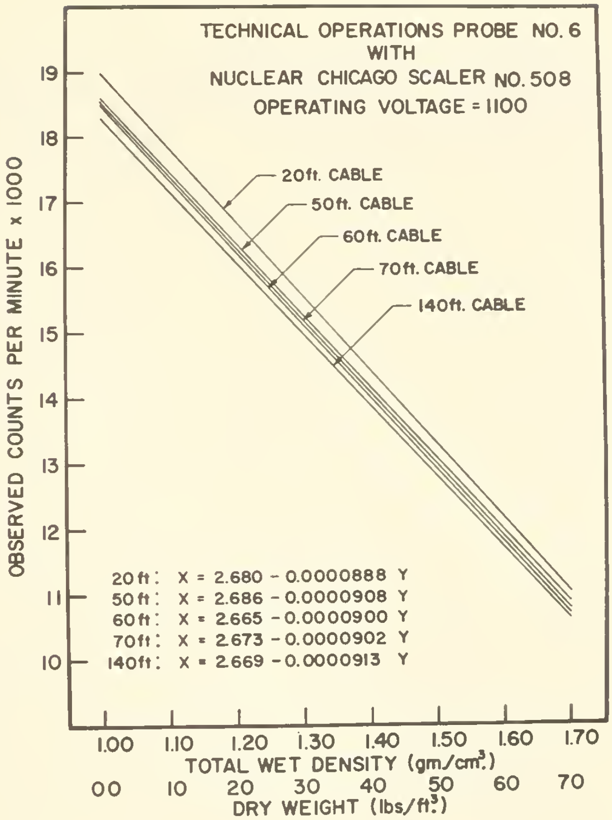


Figure 9.—A calibration curve for a gamma probe showing the effect of different lengths of connecting cable on calibration.

Geiger-Müller tubes, etc. in the probe and after replacement of components in the scaler.

Most sediments are composed of elements with a low atomic number. Gamma ray attenuation, therefore, is not unduly influenced by atomic composition of most sediments. A calibration curve prepared for northern Mississippi sediments served equally well for the Texas Blackland and for Puerto Rican sediments. It is known, however, that high concentrations of elements, such as calcium, iron, manganese, and those with atomic numbers above 27, will affect attenuation of gamma photons. To measure sediments that contain appreciable amounts of any of these elements, additional calibration curves based on materials with their particular atomic composition would be necessary.

EFFECTIVE VOLUME

The measurement of sediment density with the gamma probe has one serious limitation. The gamma probe cannot differentiate the densities of materials near interfaces, in layers, or in narrow bands. The radioactive source must be shielded to prevent direct transmission to the detector tubes. This is accomplished by a lead shield about 6 inches thick. This distance plus the length of the Geiger-Müller (GM) tubes, must be included in the diameter of the effective volume of the absorber that is affecting the flux of the

emitted gamma rays. The distance between the radioactive source and the upper end of the detector tubes in the gamma probe is about 11 inches. Experimental testing showed that the vertical sensitive length of the gamma probe is about 18 inches (fig. 10). The gamma probe is thus partially sensitive to material below the radioactive source and above the detector tubes as well as to that between the radioactive source and the GM tubes.

The drums used in calibration are 22 inches in diameter. The diameter of influence in sediment is less than this. As stated previously, when water alone surrounds the gamma probe, the 55-gallon steel drum is not an infinite volume. The addition of 5 pounds of soil material per cubic foot is sufficient to provide enough scattering and reflection of the gamma rays so that effectively none are lost from the container.

The maximum dimensions of the volume contributing to gamma probe reading are those of a spheroid approximately 18 inches in height by 20 inches in diameter. The sediment within a smaller spheroid is responsible, however, for most of the observed gamma attenuation. The center of the sensitive length, 9 inches from the tip of the probe, is regarded as the center of the sensitive volume. This position is recorded in the experimental data as the depth of the probe.

Because of the dimensions of the sensitive volume, there is no way to determine accurately the densities of materials less than about 18 inches thick. Readings can be taken each 6, 12, or 18 inches, but each measurement represents an integrated value for an 18-inch vertical. Preliminary tests have indicated that about 60 percent of the observed radiation flux is assignable to ±3 inches of the center of the sensitive volume, 30 percent to the second ±3-inch increment, and 10 percent to the third ±3-inch increment.

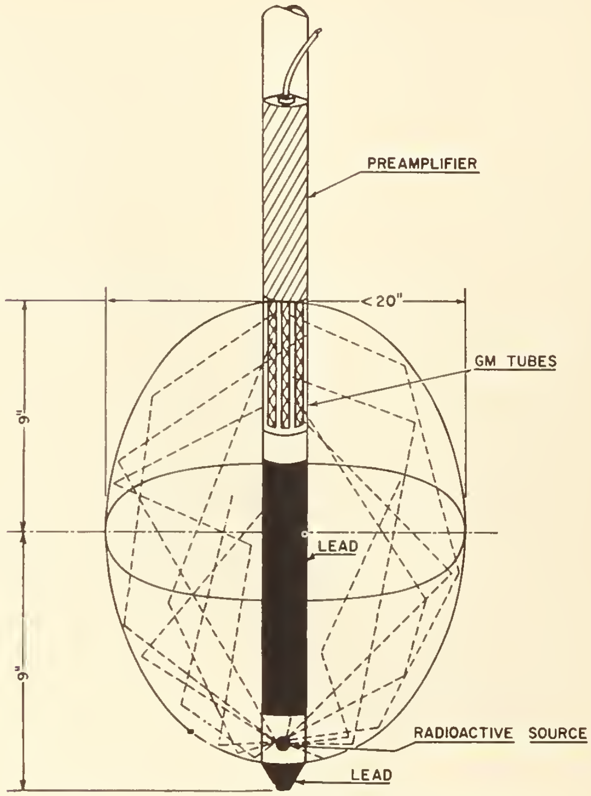


Figure 10.—Diagram of a gamma probe showing the ellipsoid of influence [after Heinemann (*4*)].

OPERATING PROCEDURE

The gamma probe has been used extensively by the Agricultural Research Service since 1959 in sediment surveys of small reservoirs. The operating procedures described are those developed by the USDA Sedimentation Laboratory for use on these reservoirs. With modifications they should apply to any situation in which the density of sediments in situ is to be determined. These methods have been used successfully in as much as 80 feet of water and in up to 18 feet of sediment.

In shallow waters, the operator can make sediment density measurements using a gamma probe while wading. One man carries the gamma probe and the necessary extension tubing to the measuring sites, while another man operates the scaler on shore. Most measurements, however, are made from a floating work area: a boat or boats (fig. 11), a raft (fig. 12), or a barge. In any situation and on all types of watercraft, techniques are similar but modified to fit the individual case.

Heinemann (*4*) used two boats, temporarily joined together with one or two 2- by 12-inch planks, to form a working platform (fig. 11). The USDA Sedimentation Laboratory uses a pontoon raft for working with the gamma probe. With any type of craft, the essential point is that the gamma probe must be maintained in a vertical position for accurate measurements and for ease and safety in raising and lowering the probe.

The need for a suitable working surface became apparent to the Agricultural Research Service during its early work on small reservoirs. Handling the gamma probe from a small boat was difficult, especially where

Figure 11.—Adaptation of two small boats as a working area in measuring sediment density with a gamma probe [after Heinemann (4)].

deeper water required the use of 20 feet or more aluminum extension tubing. From a small boat, the gamma probe cannot be pushed readily or deeply into sediments. The removal of the probe from several feet of sediment is equally difficult. Moreover, the supporting aluminum tubing can be broken if a lifting force is applied in a direction other than near vertical. Mechanical aids, such as an A-frame, pulley and cable reels, and tube clamps, are necessary to control the gamma probe and the required sections of the aluminum extension tubing. The USDA Sedimentation Laboratory now uses a pontoon raft that provides the necessary stable working surface and deck space to accommodate the electronic and accessory equipment.

The first raft used by the USDA Sedimentation Laboratory was constructed for reservoir survey work by laboratory personnel. This raft was constructed in sections so that it could be disassembled and carried by hand if necessary. Later, a commercially available pontoon craft was obtained and modified for field use (fig. 13). This craft provides a stable working area for two to four people and accomodates all needed equipment.

An open well, 4 by 4 feet, was cut in the center of the forward deck. An A-frame was then constructed over this well. One advantage of the open well is that the operators can work all around the probe and the support tubing. The well is sufficiently large that the yawing of the craft will not interfere with the vertical placement of the gamma probe and support tubing. A pulley and reel are mounted on the A-frame over the well and are used for raising and lowering the gamma probe by cable.

A choice of methods is available for stabilizing the craft in a working position. On small, shallow, reservoirs, the craft can be secured by tying to the

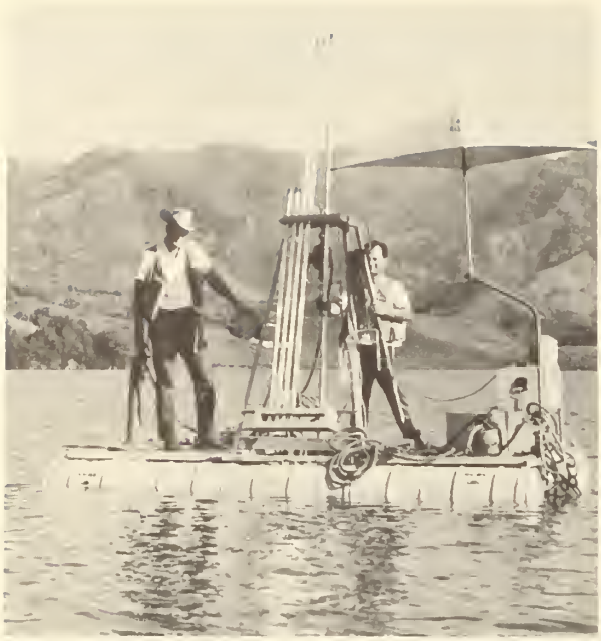


Figure 12.—USDA Sedimentation Laboratory raft with equipment necessary for measuring sediment density with a gamma probe. The man on the right is holding aluminum tubing supporting the gamma probe. Note the cable from tubing to the scaler (in box on extreme right of raft). The umbrella provides some protection to the scaler from the elements.

cable stretched across the study range (if one is available), by driving pipe into the sediment and tying to it, or by dropping small anchors. On larger and deeper reservoirs, heavy anchors that require mechanical means to raise, are necessary to hold the working craft at the site. Good seamanship is required to anchor the craft on larger and deeper reservoirs and to remain in a position suitable for measuring and for lowering and raising the gamma probe.

Preparing the Watercraft

Upon arrival at the reservoir, the operator places the survey craft in the water and loads the needed equipment on it. As a matter of water safety, operators should wear life belts or life jackets at all times when working on the water. Keep a checklist of required equipment. (See Appendix 3.)

Assembling the Equipment

When the raft reaches the sampling site, it is secured by anchoring or by fastening it to a cable extended on a range line. Two or three lengths of aluminum tubing are assembled. The connecting cable is run through this tubing and additional lengths as necessary, and the

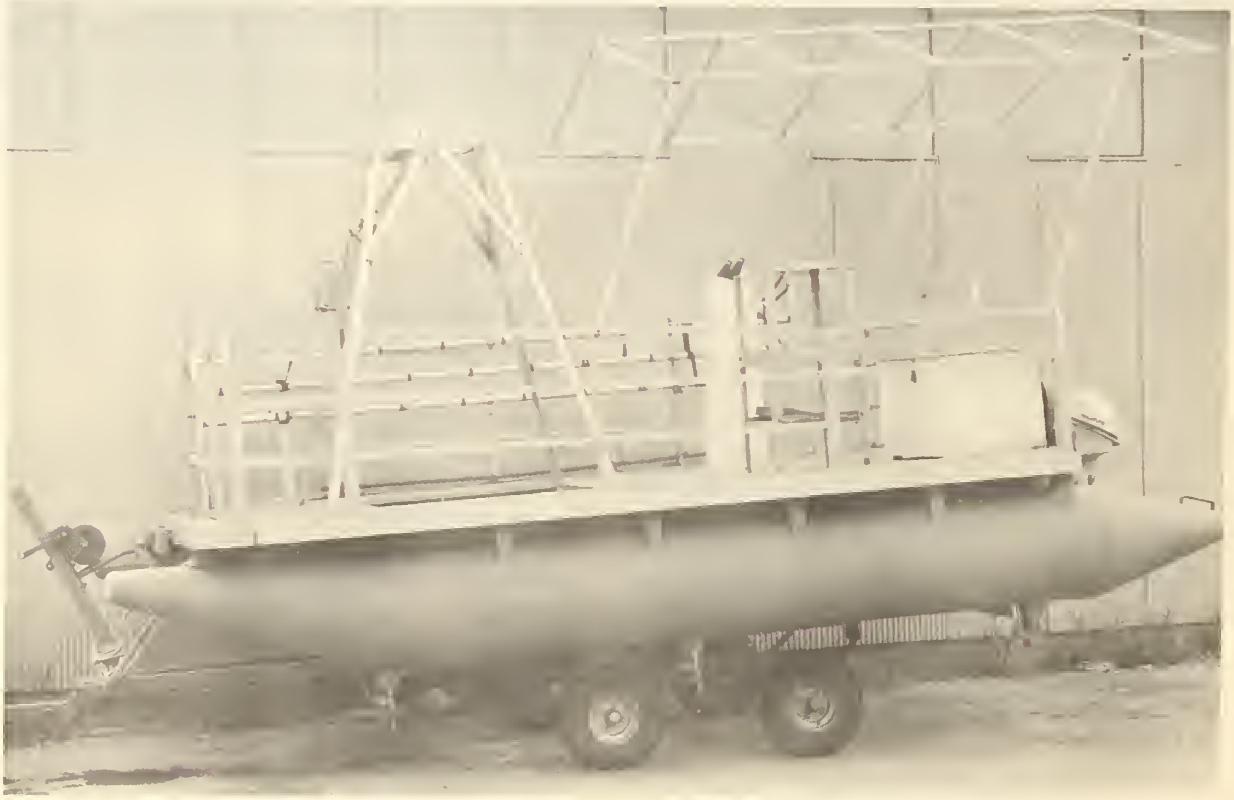


Figure 13.—View of commercial pontoon craft modified for use in sediment density surveys.

cable is connected to the scaler and the gamma probe. The tubing is screwed onto the probe. The scaler is then turned on and the voltage adjusted. It is necessary to do this as quickly as possible, because the probe and scaler should have a warmup period of 30 minutes before operation.

A watertight seal in the first aluminum tube above the gamma probe helps to protect the cable-probe connector. This seal is commonly a one-hole rubber stopper, split to accommodate the signal cable. A sealant is smeared over the cable-probe connector and the rubber-stopper seal. This assures a dry connection in less than 100 feet of water. General Electric silicone rubber sealant RTV-108 has been used for this purpose successfully. Water can be allowed to enter the rest of the connecting sections, that is, by the use of the slotted coupler section. The water will reduce the buoyancy of the column, and this allows better control.

While the scaler and probe are warming up, the operators are free to prepare the rest of the equipment for operation. Measurements of water depth can be made by sounding. Cables can be looped on special metal arms to clear the deck; aluminum tubes cleaned and threads oiled; record book prepared, etc. After the warmup period, the probe and assembled extension tube are slipped carefully into the water and the quick-clamp holder is positioned on the tubing and tightened (fig. 14). The probe and extension tubing is then controlled by the cable and reel. Another type of quick-clamp that uses two vise-grip pliers is shown in figure 15. Note the productimeter attached to the steel cable.

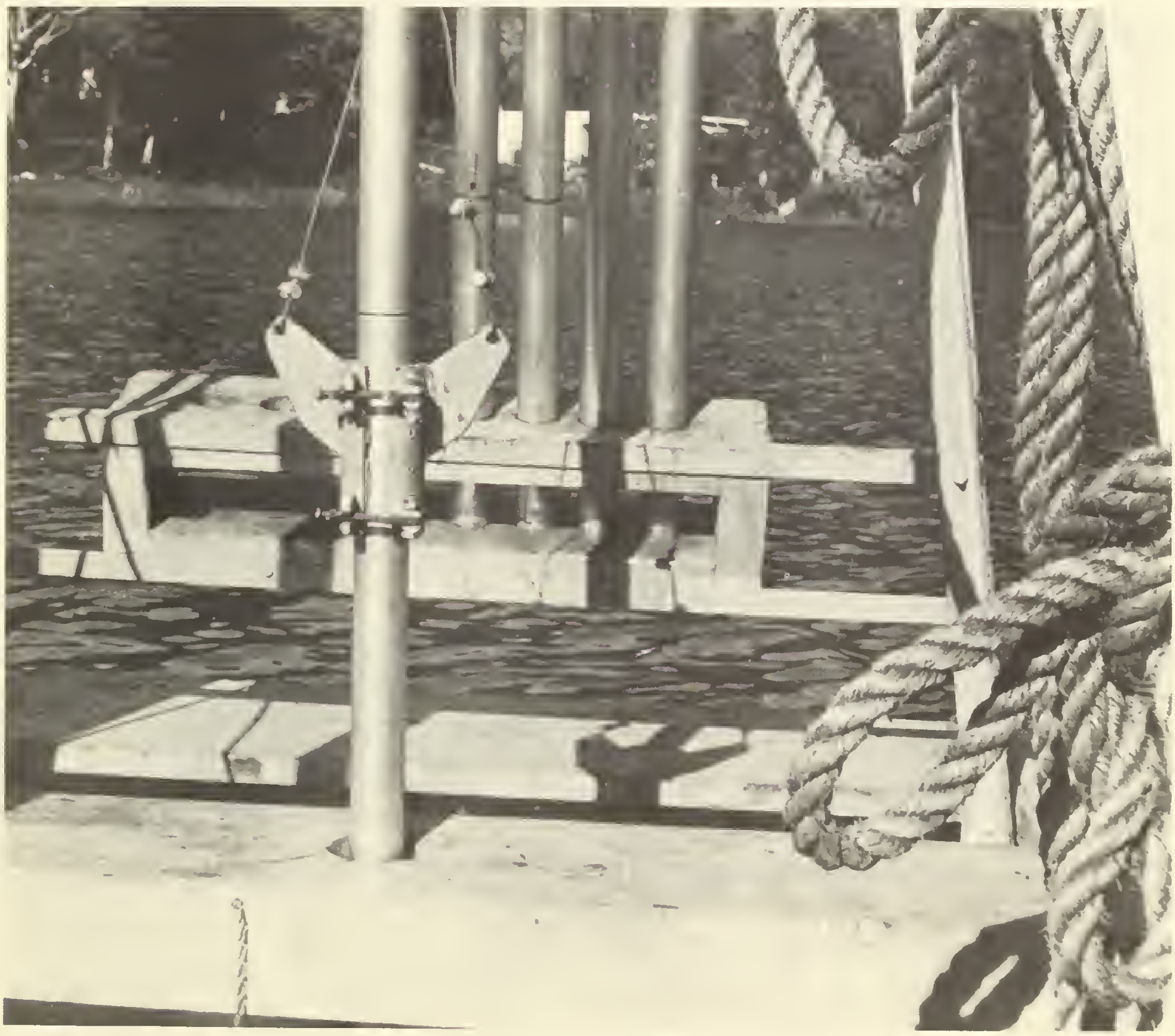


Figure 14.—Aluminum tubing supporting the probe is secured by the clamping device in which the wing nuts permit rapidly opening and closing the clamp.

Figure 15.—Aluminum extension sections attached to the probe can be secured by a quick-clamping device using two vise-grip pliers as shown.

Measuring Density

Following the warmup period, several 5-minute readings are taken with the gamma probe in at least 18 inches of water, but not in sediment. If the standard count or "water count" is within the allowable statistical error, measurements of density may be made. (See Appendix 2 for details of standard water count.)

Although all radioactive decay is random, this randomness can be described statistically. Duplicate measurements of radioactivity should agree within $\sqrt{N}$ where N is the total number of counts. This $\sqrt{N}$ is taken as the standard error of measurement, σ. At 10,000 counts per minute, $\sigma = 100$ or 1 percent. An individual measurement in water should fall within $\pm\,\sigma$ of the average water count. When this occurs, you are assured that the equipment is functioning correctly. If the reading falls outside this range of $\pm\,\sigma$, additional check counts should be made. After two or three 5-minute readings, the equipment should be "in control." If the observed readings exceed $\pm\,\sigma$, assume the malfunction of one or more components. Corrective maintenance must be continued.

With the gamma probe functioning correctly, the operator is ready to make density measurements. The gamma probe is lowered vertically until the tip is near or barely in the sediment. A 1-minute reading is taken. The gamma probe is then lowered 6 or 12 inches, depending on the measurement desired, and another reading is taken. Successive readings are made in the same manner. Duplicate readings should be taken at intervals to check performance of the probe. Readings are made only as the probe is lowered through the sediments. The effect of any disturbance of the sediment by the gamma probe is thus minimized. A "water count" should be taken at each site to check the performance of the gamma probe.

When the gamma probe first enters the sediment, it usually must be supported in each test position because of the weight of the probe and aluminum tubing. As the probe is pushed deeper into the sediment, less support usually is required. The resistance of the sediment to the probe and extension tubing increases until support of the probe is no longer needed during a measurement. The quick-clamp should not be removed from the tubing; however, slack in the cable should be provided.

When working in deep water, you must be careful when handling the long column of aluminum tubing that supports the gamma probe. Any pressure, either to force the probe deeper into the sediment or to raise the column, should be applied in as near a vertical direction to the supporting column as possible. This is to avoid breaking the tubing and to prevent the formation of a cavity around the probe. Precautions should also be taken to see that the raft, or boat platform, does not drift from its initial location while the probe is in the sediment.

In deep water, the quick-clamp should be placed on the section just above the gamma probe. It should be lowered with the probe rather than retained above the water as is commonly done at shallow depths. In deep water, the long column of aluminum tubing is subjected to forces that may cause a break. In this event, the retrieval of the gamma probe may be less of a problem if the quick-clamp is near the probe.

Experience indicates that the gamma probe can seldom be forced into the original soil underlying sediments. Sediment that has been thoroughtly dried also will be relatively impenetrable to the gamma probe. The gamma probe can be pushed into sediments which have been deposited under water and which have remained essentially under water afterwards. The depth to which a gamma probe may be pushed depends on sediment texture. In very sandy sediments, little penetration can be made. In very clayey sediments, internal friction will limit the depth of penetration of the gama probe. The latter problem can be overcome with jetting techniques in which water is pumped down through the aluminum support tubing and then allowed to escape a section above the probe. The escaping water will wash the sediment from the aluminum tubing, thereby reducing friction to a manageable level.

Changing Site Position

When the gamma probe can be pushed no farther into the sediment (because of friction or of reaching the original land surface), it is raised from the sediment. As sections emerge from the water, they can be unscrewed and removed (fig. 16). Sections beneath the slotted coupler cannot be removed from the cable unless the cable is detached from the probe or from the scaler. Where surveys are being conducted at considerable depths, the assembly of gamma probe, connecting cable, sections of aluminum tubing, and the slotted coupler should be left intact when possible. Watertight fittings are not easily obtained, and once the unit operates satisfactorily, it should not be changed.

The probe should be raised to the surface upon completion of measurements at each site and the adhering mud washed from it. A bathroom bowl brush is recommended, because the entire circumference can be washed at once. The moorings are cast off, or the

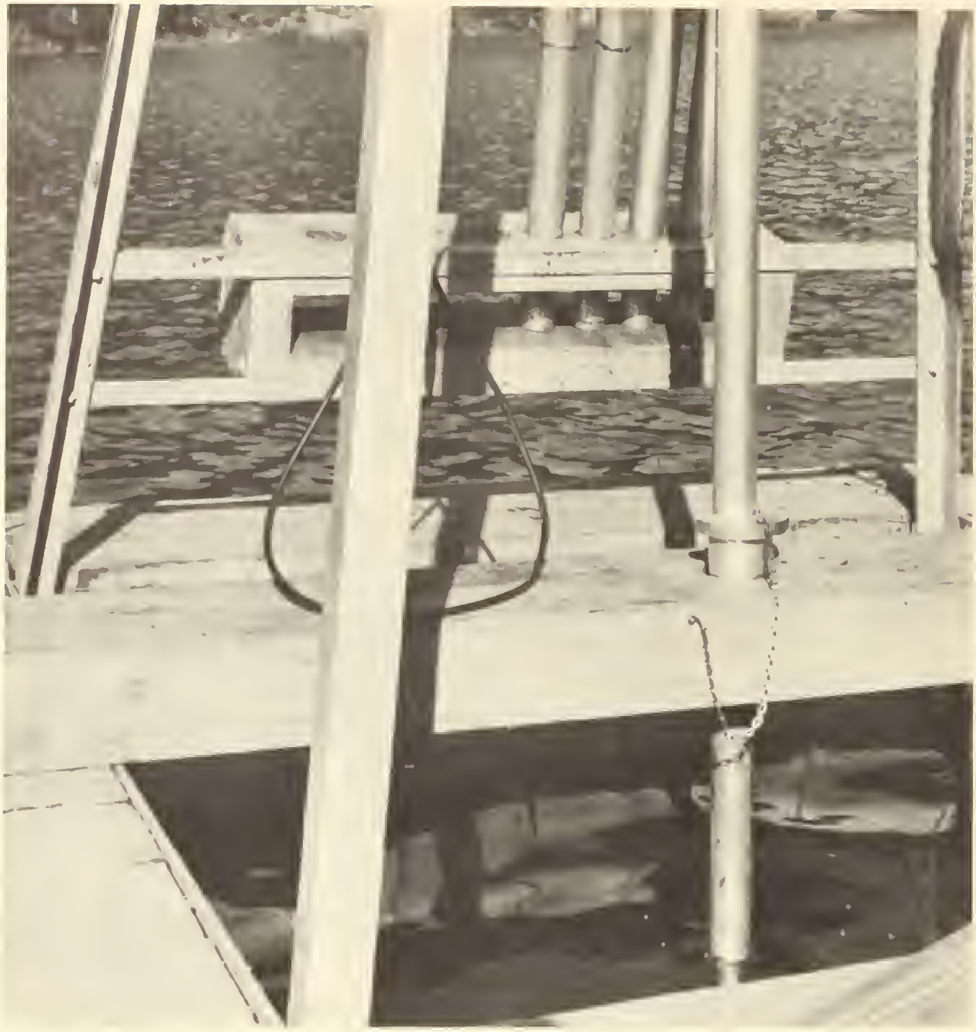


Figure 16.—Aluminum tubing and probe held in place by block and aluminum choke. This holds assembly steady while additional sections are added or removed. Note extra sections of tubing on rack in background.

anchors raised, and the raft is moved to the next location. Ordinarily, the gamma probe can be trailed in the water (1 to 2 feet deep) during the move. Because of personnel radiation hazards, it is preferable to have the gamma probe in the water or removed as far from the operating personnel as practical.

Disassembling the Equipment

On completion of the day's work, the high voltage switch on the scaler is turned off.

CAUTION. Do not disconnect the gamma probe until the scaler is turned off.

To fail to do so may produce a transient surge of current which will burn out the transistor in the preamplifier.

As the aluminum tubes are removed, all sections should be cleaned, dried, threads oiled, and finally stored in their container. The final sections, that is, those between the probe and the slotted coupler section, need not be separated if work is to be resumed on the same reservoir and a satisfactory storage space is available for this column. In handling the signal cable take care to prevent its being cut, crimped, smashed, or otherwise damaged. Care should be exercised to keep the cable connectors clean and dry. Plastic covers should be placed over the cable connectors when they are unattached. The scaler should be recharged after each day's work.

The dependability of the gamma probe will be greatly increased by proper maintenance of the unit and its accessories. Preventative, as well as corrective, maintenance should be employed. The gamma probe and the associated scaler are electronic instruments; they should be stored in dry, well-ventilated areas. Checks of their operating condition should be made periodically.

Gamma Probe

The mercury battery in the gamma probe, Mallory PM-502R, 1.35 volts, should be replaced at 6-month intervals. Other components need to be changed only when operational failure indicates need.

The "O" ring seals used to prevent entry of moisture and dirt into the chassis should be changed when worn or misshapen. If moisture gets into the probe, the chassis should be removed and dried thoroughly in a warm, not hot, atmosphere. In most cases, the gamma probe will function normally after this treatment. If not, damaged components must be replaced.

Cable connectors should be kept clean and dry at all times. Before connecting the signal cable, the connectors should be carefully checked for dirt or lint—remove it by blowing clean air on the conncetor. The exterior of the gamma probe should be kept clean and free of rust.

CAUTION: Do not handle the probe by the tip end where the radioactive source is located.

Keep this end of the probe as far away from the operators as possible. Radiation intensity decreases as the square of the distance increases. Distance and shielding are the twins that promote radiological safety. At the surface of the gamma probe near its source, the radiation level is 600 milliroentgens per hour. At the surface of the lead shield in the box, it is 100 mr./hr.; at the surface of the carrying box, 20 mr./hr.

Scaler

The batteries in the Nuclear-Chicago Model 2800, 2800A, or 5920 portable scalers must be recharged after each day's use. A charging circuit is built into each scaler. When the scaler is plugged into a 110-v. 60-cycle line, the charger is immediately activated. If the battery charge is low, the charger switches to a high (2 amp.) charging rate. When the battery voltage reaches a preset value, the charging rate is dropped to a holding (40 mamp.) or "trickle charge." When this occurs a light on the control panel is illuminated.

On the underside of the control panel, there is a switch by which the charger can be manually switched to the full charging rate. Normally this switch is on "automatic." A switch near the battery light permits you to check the condition of the battery. When this switch is engaged, the battery light is energized—the intensity of the charge is reflected in the brightness of the light. The wet cell battery provided in the Nuclear-Chicago 2800 or 2800A scaler will operate the gamma probe for 12 to 24 months before replacement is necessary. The dry cell battery in the model 5920 scaler can be recharged many times before replacement is necessary.

On the panel board, a "Test-Use" switch controls the display of a test or of a measuring signal. In the test position, the scaler should record 3,600 c.p.m. when powered by the 110-v. 60-cycle line. When battery powered, the test circuit should show about 7,200 c.p.m. The failure of either test indicates malfunction of the counting circuit.

Accessory Equipment

Coaxial cable.—Primarily, you should be concerned with preventing breakage and contamination of the cable and the cable connectors. Careful handling of the cable is essential at all times. Cuts or sharp bends may break the signal cable or permit entry of moisture which will short out the high voltage. The necessity for cleanliness of the connectors has been discussed above.

Aluminum tubing.—The threads on the aluminum tubing sections should be protected. Following use, the threaded section should be cleaned and oiled. During use, add oil (SAE-10) to the threads from time to time as needed. Protect the tubes from knocks and bumps. When not in use, the ends may be taped.

On the raft used by the USDA Sedimentation Laboratory, a rack was constructed to hold the sections in a near-vertical position (fig. 12). Not only are the tubes protected, but they are also arranged for the easiest use.

In attaching a section of aluminum tubing, tightening by hand is sufficient. However, when the sections are being taken apart, wrenches are frequently necessary. For this purpose, strap wrenches are required. No metal to metal contact should be allowed, because the soft aluminum tubes are easily marred. For ease of operation and to prevent injury, it is essential that no burrs or flared or rough edges occur on the

aluminum tubes. Operators will find the use of gloves impractical at times, because a firm grip cannot be maintained on a heavy string of wet aluminum sections with a gloved hand.

A clamp or choke (fig. 16) is helpful in holding the aluminum tubing while sections are being added or removed. Clamps or chokes should not mark or mar the aluminum tubing, and units of wood or aluminum have proven satisfactory.

Trouble shooting

A table of troubleshooting hints is provided by Nuclear-Chicago in their scaler manual. Specific directions are given. In general, malfunction of the gamma probe can be traced to (in probable order of occurrence): (1) A cable or cable connector failure, (2) mercury battery in the probe, (3) a transistor in the probe, (4) a short in a preamplifier component in the probe, or (5) scaler. Malfunction of the system may appear in one of several ways—continuous high speed, spurious or erratic counting, or no counts at all.

When erratic or spurious counting occurs, you should check and tighten all cable connections. If you note spurious counts while wiggling the cable, suspect a cable break or short. If counting ceases after submergence of the probe, most probably water has leaked into the probe cable connection. Erratic performance of the gamma probe, particularly after handling or transporting, may indicate that some component of the probe is being intermittently shorted on the steel housing. Failure to obtain standard counts in water can often be traced to faulty drive or glow tubes in the scaler counting circuit. In the event that no counts are observed when the "count" switch is turned on, check to be sure that the high voltage control is set at the proper value.

PROCESSING DATA

For most routine sediment surveys, density determinations based on 1-minute readings with the gamma probe are adequate. In sediment, the count rate with the Technical Operations gamma probe is frequently 10,000 counts per minute or more. At 10,000 c.p.m. the standard error is 1 percent. Variations between duplicate field measurements seldom exceed this error. For a density of 70 lb./cu. ft., this error approximates 0.7 lb./cu. ft. Routinely, the error is seldom found to exceed 0.5 lb./cu. ft. By employing longer counting periods, this error can be reduced. The error for a 10-minute count would approximate 0.15-0.26 lb./cu. ft.

The center of the sensitive length of the probe, 9 inches from the tip, is considered the center of the volume of sediment whose density is being measured. As described earlier, measurement is most strongly influenced by the density of the material nearest this point and least by that material near the surface of the measured spheroid. If readings are taken at 12-inch increments, there is little effect on a given reading from adjoining measurements while the probe is lowered into the sediment. However, if readings are taken at 6-inch increments, some 40 percent of the observed reading is due to the density of the previous increment. The user of the gamma probe will need to consider these factors in making and reporting density values for sediment.

As previously noted, the error in field measurements seldom exceeds 0.5 lb./cu. ft. Results should not be reported in units smaller than 0.1 lb./cu. ft. The observed densities are total densities. It is possible however to calculate the dry weight of sediment by knowing its average specific gravity or by using an assumed value (*4*). If one assumes a specific gravity of 2.65, the weight of dry sediment is given (for practical purposes) by the expression:

Weight of dry sediment = Wet density - 1.00
(lb./cu. ft.)   (gm./cc.)

That is, sediment with a measured wet density of 1.54 contains 54 pounds of dry sediment per cubic foot.

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Specifications for Gamma Probe

Probe is to be used in conjunction with a Nuclear-Chicago Model 5920 portable scaler for determining densities of sediment beneath waters to depths of ________ feet. The probe shall consist of: A stainless steel seamless tube, type 303, 304, or 316; 1½-inch O.D. by 0.065 inch thickness.

Within the probe will be a 3- to 4-millicurie source of Ra-226, 6 inches of lead shielding, detector tubes, electronics, and power supplies capable of operating the unit under the specified conditions. Signals and power are to be conveyed by a cable to the surface (and the N/C scaler). The cable is to be a Belden 8410 or equivalent, with a suitable watertight connection (Mecca) to the probe. This connection is to be readily made and unmade without damaging the cable, connector, or electronic components. Transient currents must be eliminated in the circuity. The entire contents of the probe are to be on a slide-in chassis. This chassis is to be sealed from the environment by multiple and suitable "O" rings and precision milling of closure components. Cable connections are to be made within the threaded connector designed to fit aluminum extension tubing for controlling unit under water.

The aluminum extension pipes, – in number, each – feet in length, are described in figure 17. (These aluminum tubes may be obtained independently of the gamma probes. Specifications, however, are given here.) The probe to tubing connection shall consist of a threaded probe connector specified as: thread, 1-5/16 inch, 14 UN-3A, pitch diameter, 1.2584 maximum, 1.2541 minimum. An "O" ring seal between probe and pipe is necessary. Any enlargement at the connector end of the probe must be minimal and completely streamlined. Holding screws should be flush.

Entire unit is to be essentially equivalent to Technical Operations, Inc. Model 497 sediment density probe, with the addition of operating specifications under ________ foot depth of water, and the inclusion of ________ feet of cable and ________ feet of aluminum piping in ________ foot sections.

Unit is to be supplied with carrying box, cable, (aluminum tubing), and instruction manual.

Specifications for Portable Scaler

Construction. Modular, solid state, repairable, printed circuit construction.

Input. Accepts negative pulse amplitudes from 50 mv. to 20 v. with a rise time of 2 microseconds or less. Pulse height sensitivity, internally adjustable, is factory set at 200 mv.

Resolving time. 10 microseconds.

Count capacity. Zero through 99,999 counts.

Preset timer. Automatically stops the count mode after selected interval of ¼, ½, 1, or 2 minutes. Manual switch position permits continuous counting without the preset timer function.

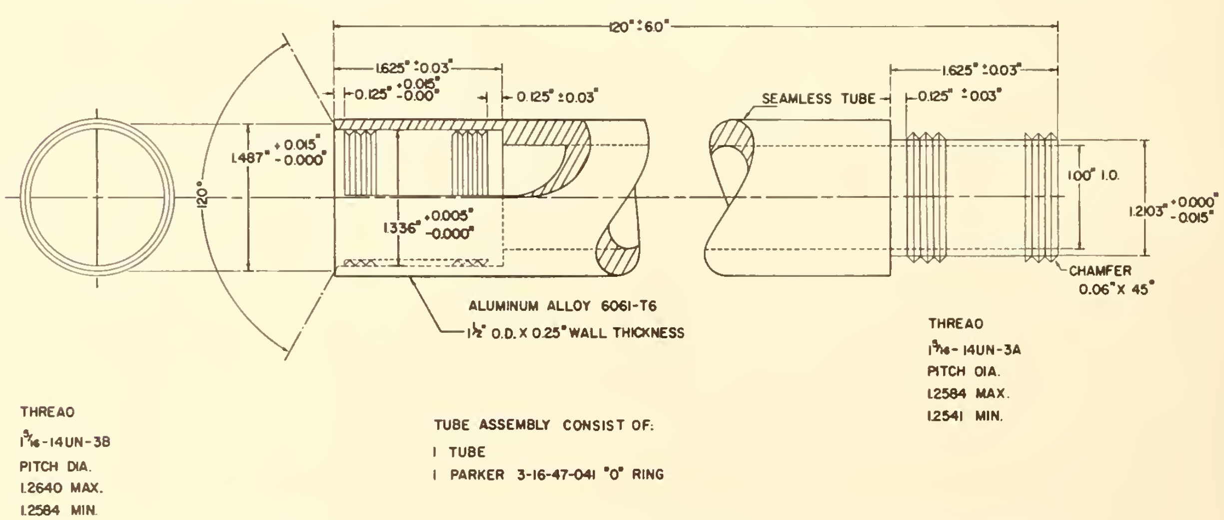

Figure 17.—Drawing of aluminum extension tubing showing construction details. Length is optional.

Timer stability. Within 0.01 percent at 75° F.; within 0.2 percent from 0° to 140.°

Readout display. Five in-line neon decades for digital display.

Test. Internal oscillator provides a test signal for instrument check. When an external 60 cycle power source is connected, test oscillator is synchronized at 120 p.p.s.

High voltage supply. Level set with direct reading front panel controls for range of +300 through +1500 v.

High voltage stability. Better than 0.1 percent over full range in power supply tolerances.

Power supply. Assembled battery pack contains six "D" size nickel-cadmium cells series connected for 7.5-v. output. Fully charged battery pack provides over 20 hours operating time with less than 1.5-w. average power consumption. Unit has built-in circuits for recharging from external AC or DC power source.

External power. 115-v. AC (230 v. optional), or 12-v. DC external battery.

Front panel. 8" x 12" dark, nonglare finish.

Dimensions. 12" wide x 8" high x 7" deep, not including cover or handles.

Weight. 16 pounds.

Accessories supplied. One 115-v. AC power line cord with safety guard plug, and one adapter to convert probes with MS type connectors to the new, quick-disconnect type.

Accessory available. Cable with two battery clips for operation and recharging from a 12-v. DC storage battery.

Controls:

Fine high voltage. Continuously variable with 100-v. range: control linearity better than 0.1 percent.

Coarse high voltage. Twelve positions for 300 through 1,400 v. in 100-v. increments; linearity better than 0.1 percent.

Start. Pushbutton switch actuates scaler and timer counting cycle.

Stop. Pushbutton to stop counting manually.

Reset. Pushbutton resets the five decades and the timing circuit to zero.

Display. Pushbutton increases current to brighten decade display lamps.

Master. Five-position power switch to select "Off," "Moisture," "Density," "Test," or "Charge" circuits and power conditions as required.

Preset minute. Five positions: ¼ minute, ½ minute, 1 minute, 2 minutes, or Manual (disables the automatic timer stop function).

Interlock. Automatically turns power off when the cover is closed over the front panel.

Indicators:

Count. Lights when scaler is in its Count mode.

Low battery. Lights when internal storage battery requires recharging.

Decade display. Five decade scaling units with in-line numerical readout.

Connectors:

Input. Quick-disconnect type with circuits for low voltage to probe preamplifier, high voltage to detector, and signal input from the probe; also includes probe function control.

External power. Accepts 115 v. AC through one pair of contacts, or 12 v. DC through an alternate pair of contacts. The mating cables are prewired to channel the power to the proper contacts.

Procedure Sheet

Title: Calibration of a Gamma Probe.

Objective:

To prepare in the laboratory a calibration curve that may be used to convert field readings obtained with the gamma probe into values of density in lb./cu. ft.

Procedure:

Assemble equipment:

- Gamma probe, cable, and scaler.
- Three or four 55-gallon drums, tare weights known.
- Scales, a source of water, yard stick, point gage, brush for cleaning probe, and A-frame and chain hoist for moving drums.

Prepare a water standard:

- Add 300 lb. water to a drum.
- Measure and record:
  (1) Height of drum at center (H_c) and edges (H_e) in inches (fig. 18).
  (2) Diameter (D) of drum in inches.
  (3) Depth (h) of the water in inches.
  (4) Distance from top of drum to water surface (p_1) with point gage.
  (5) Total weight of drum and contents in lb. (W_o).

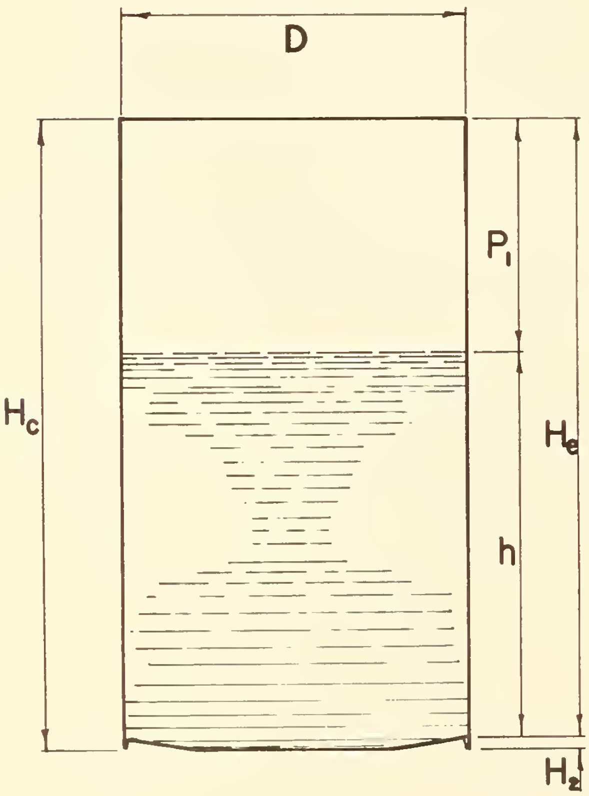

Figure 18.—Sketch of a steel drum used for calibration of the gamma probe. Symbols indicate needed measurements.

Take a water reading:

- Connect probe, cable, and scaler.
- Turn on scaler, adjust high voltage to proper value, and allow to warm up for 30 minutes.
- Take a 10-minute reading with the probe suspended in center of a drum of water. Make certain probe is at least 4 inches from the bottom of the drum and is submerged to set screws. The 10-minute reading should be within $\pm\sqrt{N}$ of the long time average of 10-minute water readings.

Take a sample reading:

- Add the desired amount of soil to the water.
- Mix thoroughly. Use a power stirrer for complete mixing.
- Measure the total weight and the distance from the top of the drum to the water-soil surface (p_2) with point gage.
- Make two or more 5-minute readings with probe suspended in the clay mixture. See step 3 under "Take a water reading."
- Wash clay from probe with brush after making measurement.

Make measurement in a number of samples with different densities.

- Repeat readings with probe suspended in the clay mixture.
- Make a 5-minute water reading before each sample reading.

Calculation:

Convert data into values of weight and volume.

- Weight = W_o - Tare Weight
- Volume = $V_{cylinder} + V_{curved\ base}$

(1) $V_c = \frac{\pi D^2}{4} \times \frac{1}{1728} \times h_n$ cu. ft.

where $h_n = h + (p_2 - p_1)(12)$ inches

(2) $V_{cb} = \frac{1}{6}\pi H_2 \left(\frac{3D^2}{4} + H_2^2\right) \times \frac{1}{1728}$ cu. ft.

where $H_2 = H_c - H_e$ and p_2 and p_1 are point gage readings in feet.

Calculate the density of the sample:

$$\text{Density} = \frac{\text{Weight}}{\text{Volume}} \text{ lb/cu. ft.}$$

Plot the values calculated for the density of the samples against the readings made at those points with the gamma probe. The data should plot as a straight line on linear graph paper (fig. 8).

APPENDIX 3

Check List For Gamma Probe And Equipment For Sediment Survey

Gamma probe in carrying box:

- Cable
- Coupling section
- Probe accessories—
  - (1) Spare cable
  - (2) Spare connectors
  - (3) Volt-ohm meter
  - (4) Soldering iron and solder
  - (5) Small tools
  - (6) Brushes for cleaning
  - (7) Steel brush
  - (8) Operation manual
  - (9) Record book and pencil
  - (10) Stopwatches, two (not required with Model 2800A or 5920)
  - (11) Spare battery, Mallory PM 502R, 1.35 volts

Nuclear-Chicago scaler, complete:

- Charging cable
- Distilled water (not necessary for Model 5920)
- Accessories—
  - (1) Operations manual
  - (2) Spare tubes, transistors, and diodes
  - (3) Carrying box with foam padding

Aluminum pipes for probe, complete in carrying box.

Sounding rod or sonic fathometer.

Boat, motor, and gasoline can.

Raft, complete:

- Productimeter
- Umbrella
- Cable, reel, and stand
- Box holder for scaler
- Probe clamp
- "C" clamps
- Anchors or other mooring device(s)

Personnel equipment:

- Water jug
- Life belts
- First aid kit and snake bite kit
- Film badges (personnel dosimeters)
- Hats
- Sunglasses
- Gloves

Other equipment:

- Tool box, containing—
  - (1) Strap wrenches
  - (2) Oil can and oil
  - (3) Open end wrench for raft bolts
  - (4) Spare bolts and nuts
  - (5) Adjustable wrenches, small and medium
  - (6) Maul for installing "dead man"
  - (7) Short pipe for "dead man"
- Metal tape
- Bundle of rags

APPENDIX 4

Procedure Sheet

Title: Operating plateau for a gamma probe.

Objective:

To determine the operating voltage of the gamma probe.

Procedure:

Assemble and prepare equipment.

- Connect cable to gamma probe and to scaler.
- Suspend gamma probe in 55-gallon drum of water.

After making sure that the high voltage control is turned all the way down, turn the scaler on.

- Allow 30 minutes warmup time.
- Turn count switch to count position.

Gradually increase the high voltage until the scaler begins to count.

At this point, begin taking 1-minute readings.

- Take a reading at every 25-v. increase.
- Do not increase voltage beyond the point at which the count rate shows a sudden rise.
- When this point is reached, turn the voltage down.

Calculations:

Plot the counts per minute as the ordinate against voltage as the abscissa on linear graph paper in the manner shown in figure 6—

- For the ordinate, set the scale at approximately four thousand counts per inch.
- For the abscissa, set the scale at about 25 v. per inch.

Select a point approximately in the middle of the plateau as the proper operating voltage.

Attach a label to the scaler indicating the proper operating voltage for the gamma probe.

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